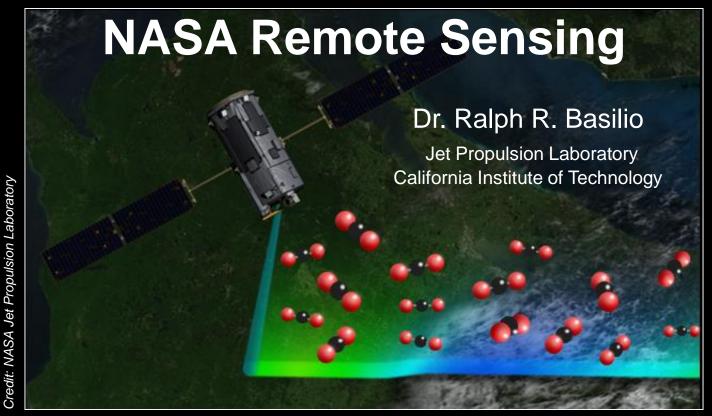
# Earth and Environmental Engineering Colloquium – Fall 2017 The Fu Foundation School of Engineering and Applied Sciences (SEAS) Columbia University in the City of New York

Thursday, 02 November 2017, 11:40 am – 12:55 pm ET, 702 Hamilton Hall



Reference: Clearance No. CL#17-xxxx

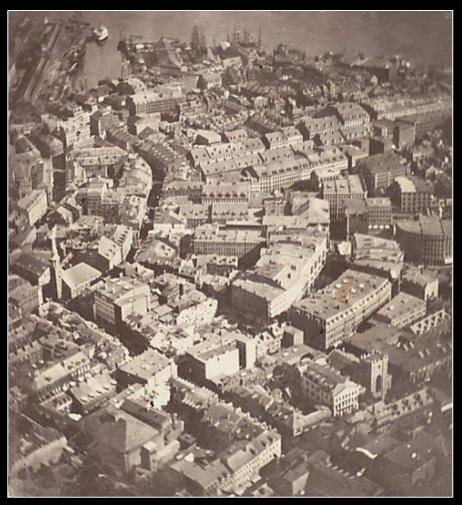


The term "remote sensing," first used in the United States in the 1950s by Ms. Evelyn Pruitt of the U.S. Office of Naval Research, is now commonly used to describe the science—and art—of identifying, observing, and measuring an object without coming into direct contact with it.

- NASA Earth Observatory



## "Boston, as the Eagle and Wild Goose See It"



Credit: James Wallace Black, 1860



## First Photograph of the Earth from Space



Credit: White Sands Missile Range/Applied Physics Laboratory, 24 October 1946

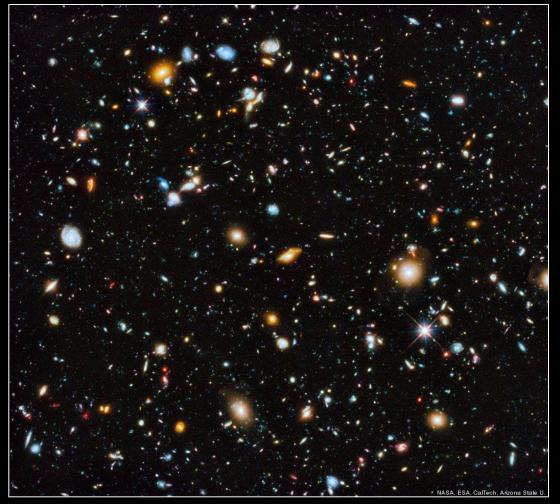


## First Photograph of the Earth from the Moon



Credit: NASA, Lunar Orbiter, 23 August 1966

## Hubble Space Telescope (HST) Ultra Deep Field Image



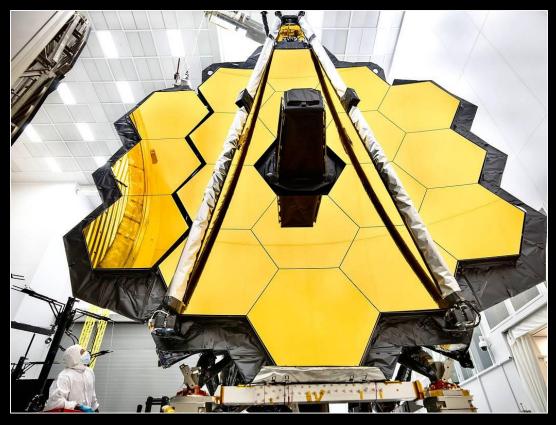
Credit: NASA, ESA, and G. Bacon (STScI), 2014



Credit: NASA, ESA, and G. Bacon (STScI), 2014



# The James Webb Space Telescope (JWST), to launch in 2019, will see further back in time than any other any other observatory before



Credit: NASA, May 2017



# Until recently NASA spaceflight missions have generally served a singular need

## ...that of science/research



### However,

## ...The times are a changin'

- Title of song by Bob Dylan, 2016 Nobel Prize for Literature



### A Concerted Effort at JPL



Combining system engineering expertise with advanced technologies and science expertise to provide reliable and accurate information (e.g., science data applications)

Credit: Caltech/Jet Propulsion Laboratory



## Orbiting Carbon Observatory-2 (OCO-2)

Credit: Caltech/Jet Propulsion Laboratory

Vent Pipe

Primary Instrument
Assembly (PIA)

Telescope Opening

Baffle/Calibration
Assembly (BCA)

Optical Bench
Assembly (OBA)

Remote Electronics
Module (REM)

(Basilio, Pollock, Hunyadi-Lay, 2014)



## 02 July 2014 Launch



Credit: NASA/Jet Propulsion Laboratory



Credit: Orbital Sciences Corporation



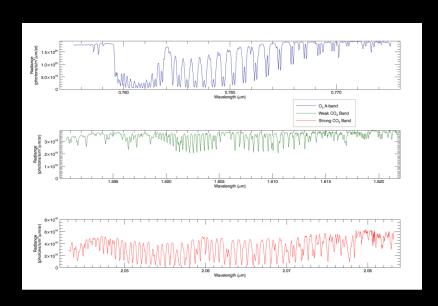
Credit: NASA

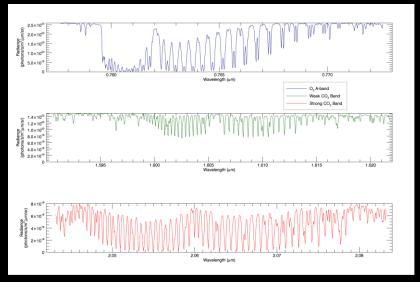


Credit: NASA



## Beautiful 'First Light' Spectra





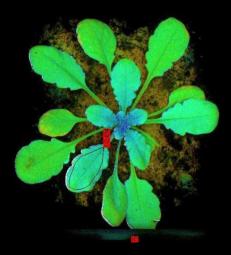
From Ground Test (April 2012)

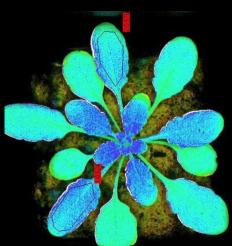
In-Flight Data (06 August 2014)

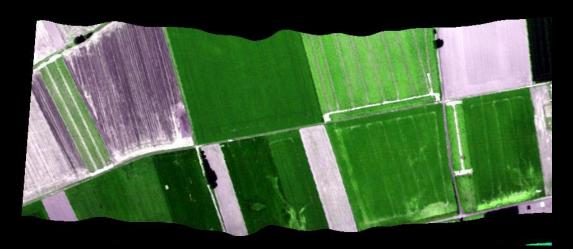
(Basilio, Pollock, Hunyadi-Lay, 2014)



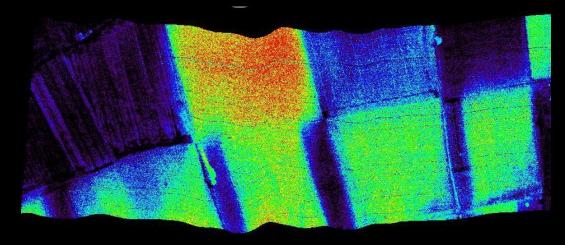
## Plants Grow and Plants Glow



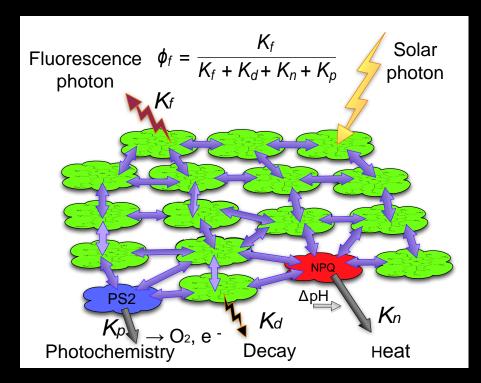




Credit: ESA / U. Rascher, Forschungszentrum Jülich

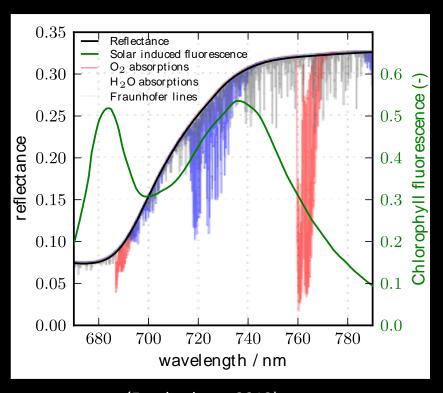






(Frankenberg et al., 2013)

## Solar-Induced chlorophyll Fluorescence (SIF)



(Frankenberg, 2013)





# Science Data Application: Contribution to Agricultural Research

#### **@AGU**PUBLICATIONS

#### **Geophysical Research Letters**

#### RESEARCH LETTER

10.1002/2016GL070775

Key Points:

GPP scales linearly with SIF from
instandaneous to monthly time scales

Aggregating ecosystem GPP-SIF
functions yield a representative
landscape relation that matched one
obtained directly using fall tower GPP

GPP-SIF relations showed sensitivity
to plant physiology but not

Supporting Information:

Correspondence to: J. D. Wood,

#### Citation: Wood I D. T. I Griffis J M. Baker

Wood, J. D., T. J., Griffis, J. M. Baker, C. Frankenberg, M. Verma, and K. Yuen (2016), Multiscale analyses of solarinduced florescence and gross primary production, Geophys. Res. Lett., 43, doi:10.1002/2016GL070775.

Received 8 AUG 2016 Accepted 18 NOV 2016 Accepted article online 22 NOV 2016 Multiscale analyses of solar-induced florescence and gross primary production

Jeffrey D. Wood<sup>1,2</sup> , Timothy J. Griffis<sup>1</sup> , John M. Baker<sup>1,3</sup> , Christian Frankenberg<sup>4,5</sup> , Manish Verma<sup>6</sup> , and Karen Yuen<sup>5</sup>

Department of Soil, Water and Climate, University of Mineseta, Twin Cities, Saint Paul, Mineseto, USA, "New at School of Natural Resources, University of Missouri, Columbia, Missouri, USA, "Soil and Water Research Unit, USDA-ARS, Saint Paul, Minnesou, USA, "Division of Geological and Planetary Sciences, California Institute of Technology, Pasadera, California, USA," Det Propulsion, Laboratory, California Institute of Technology, Pasadera, California, USA, "Consulting for Statistics, Computing, and Analysis Research, University of Michigan, And Arbo, Michigan, USA."

Abstract Solar-induced fluorescence (SIF) has shown great promise for probing spatiotemporal variations in terrestrial gross primary production (GPP), the largest component flux of the global carbon cycle. However, scale mismatches between SIF and ground-based GPP have posed challenges toward fully exploiting these data. We used SIF obtained at high spatial sampling rates and resolution by NASA's Orbiting Carbon Observatory-2 statellite to elucidate GPP-SIF relationships across space and time in the U.S. Commelter. Some best storage consistent across instantaneous to monthly time scales were obtained for core occeptions and for a heterogeneous landscape based on all those observations. Although the slope of the corn function was –56% higher than for the landscape. SIF was similar for corn (Ca) and soybean (C<sub>3</sub>). Taken together, there is strong observational evidence showing robust linear GPP-SIF scaling that is sensitive to plant physiology but insensitive to the spatial or temporal scale.

#### 1. Introduction

Terrestrial gross primary production (GPP) is the largest global carbon (C) flux [Beer et al., 2010]. Accurately representing GPP in coupled carbon-climate models is thus of great importance, but a lack of observational constraints at regional to global scales has impeded the development and evaluation of models [Friedlingstein, 2015]. Therefore, obtaining better constraints on spatiotemporal variations in GPP is a subject of great interest (Anay et al., 2015). The advent of satellite-based monitoring of solar-induced fluorescence (SIF) has opened new avenues for probing regional-to-global photosynthesis [Frankenberg et al., 2011b; Joiner et al., 2011, 2014; Guanter et al., 2014; Porcar-Castell et al., 2014; Duveiller and Cescatti, 2016). An important advantage of SIF is that it is more tightly coupled to physiological processes than vegetation indices such as the normalized difference vegetation index (NDVI) [Rossini et al., 2015] or enhanced vegetation index (EVI) that are not sensitive to dynamic changes in physiological functioning and light-use efficiencies (LUEs). For instance, the onset and shutdown of photosynthesis, which is not mechanistically linked to leaf greenness, is better constrained by SIF [Joiner et al., 2014]. However, to fully exploit the potential of SIF, a better understanding of the relationship between SIF and GPP is needed to construct seasonal and annual budgets. This is particularly important for agroecosystems where despite a similar coupling between the electron transport rate (ETR) and fluorescence, different electron-use efficiencies (EUEs) and carbon-use efficiencies (CUEs) can give rise to different SIF-GPP relationship in C3 and C4 crops [Y, Zhang et al., 2014]. In the Corn Belt, which is dominated by corn (Ca) and soybeans (Ca), the GPP of the latter is only ~55% of the former [Suyker and Verma, 2012]. Understanding how Ca and Ca photosynthesis affects the relationship between SIF and GPP is thus important for utilizing SIF toward reliable estimation of local and regional budgets of photosynthetic carbon assimilation

The existence of a relationship between fluorescence and the ETR of photosystem it is well established at nelocular to led flevels over short time scales, largely based on active fluorimetry measurements [Seler, 2008]. In contrast remote sensing measures passive fluorescence induced by solar irradiance, with significant knowledge gaps regarding quantitative relations with photosynthesis [Prozer-Castell et al., 2014, Emplicially, model and flux tower (PPS scales linearly with SF observed (e.g., Global Cozen Monitoring Experiment 2, (GOME-2) or Greenhouse Gasso Observing Satellite (GOSAT)) at course spatial resolution and bisweekly to annual time scales [Finarkenberg et al., 2011b] in a fashint that is somewhat ecosystem

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WOOD ET AL.

MULTISCALE GPP-SIF RELATIONS

- Terrestrial Gross Primary Production (GPP) is the largest global carbon flux
- Ground-based GPP compared with space-based SIF
- Linear GPP-SIF relationships were found that were robust in both space and time
- GPP derived from SIF found to be a better regional-scale estimator than that obtained through tall towers alone or other space-based measurements

(Wood et al., 2016)



## Western States Water Mission (WSWM)

Jet Propulsion Laboratory, California Institute of Technology

#### The Western States Water Mission



CUAHSI Hydroinformatics meeting 16 July 2015





(Reager, CUASI presentation, 2015)

## THE JET PROPULSION LABORATORY (JPL) WESTERN STATES WATER MISSION (WSWM)

A Prototype for a Hyper-Resolution Hydrological Modeling and Data Analytics & Visualization Platform

James S. Eamiglietti, Ralph R. Başilio, Daniel J. Crichton, Cedric H. David, Thomas G. Farr, Stephanie L. Granger, Jonathan M. Hobbs, Steven R. Levog, Shan Maltotra, Catalina Qajda, Gregory B. Osterman, John T. Beager, Michael Buecker, Diroitros Stampoullis, Amy R. Tagapsrud, Michael J. Turgop

The Jet Propulsion Laboratory, California Institute of Technology has developed a working prototype of a hydrological and data science web-based tool that will serve the needs of science/research, data applications, and informed decision-making.

INTRODUCTION. Water makes up 50% to 75% of the human body weight. It is an excellent solvent that allows for the transportation of nutrients and waste, it serves as a lubricant for proper food digestion and joint mobility, and it serves to regulate our body temperature through perspiration and

AFFILIATIONS: Executive Beeilior Crichton, David, Farr, Granger, Hobbs, Lewas, Malhatre, Caida, Osterman, Beegas, Bueckant, transpeard, and Turman Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA. Stampaube - University of California, Los Angeles.

CORRESPONDING AUTHOR: James S. Earviglietti, James S. Famiolietti@iol.nasa.gov

The abstract for this article can be found in this issue, following the table of contents.

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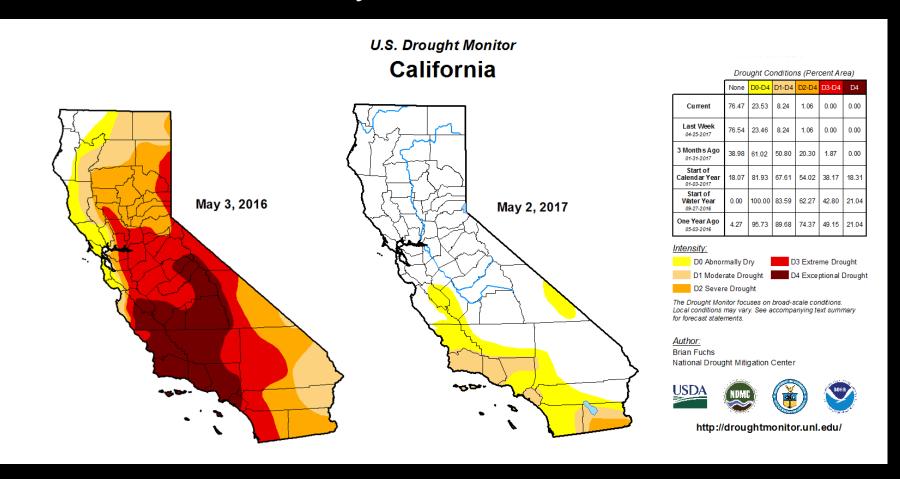
evaporation. In fact, water is the essence of life on Earth. Without it there would be no animals, plants, and simple life forms. Every living thing requires dependable, clean water to thrive. There will be greater demands as the human population continues to grow: the 8 billion mark will be reached by the middle of the next decade with an ever-increasing growth rate predicted beyond. However, the urgency in better estimating current and future amounts is already being felt close to home, namely the state in which we live. California recently faced one of the most severe droughts in the state's recorded history: given relatively low rainfall amounts and unquenchable thirst for domestic, industrial, agriculture, and environment use, reservoir levels dropped to unprecedentedly low levels. Meanwhile, groundwater in aquifers, the strategic water supply reserve during periods of prolonged drought, continues to be depleted at unsustainable rates. While voluntary, and in increasingly more regions, mandatory water conservation measures have been

[Publication Name, Date, and Page Number]

(Famiglietti et al., pre-publication 2017)



## Water is Always of Interest in the West!





## System Highlights

- Flight project approach to development and validation
- Input of space-based, airborne, and in situ sensor data
- Use of land surface models
- Multi-sensor data assimilation
- High (hyper-scale) spatial resolution
- Down-scaled estimates of groundwater
- Uncertainty quantification
- Data science (scalability, analytics, and visualization)



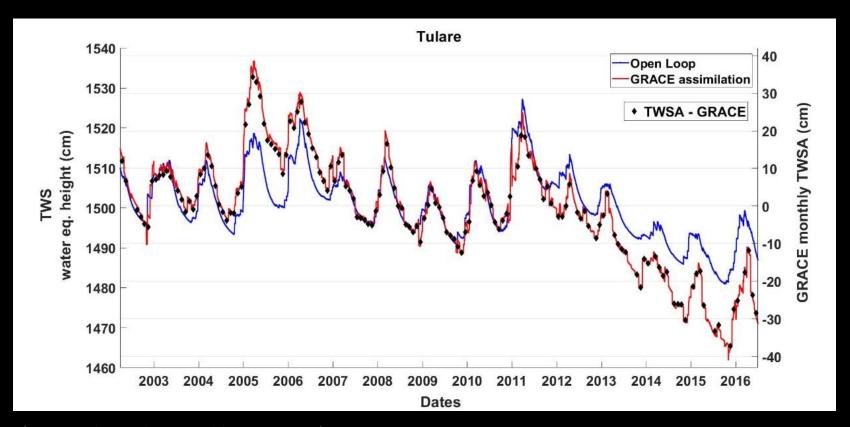
## Twin GRACE Spacecraft



Credit: NASA/Caltech-Jet Propulsion Laboratory



## Data Assimilation Improves the Estimates of Total Water Storage (TWS)



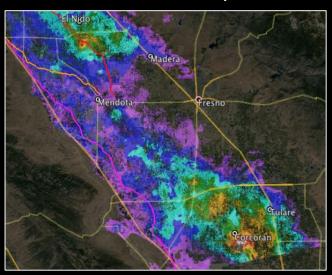
(Stampoulis et al., pre-publication 2017)



### Science/Research:

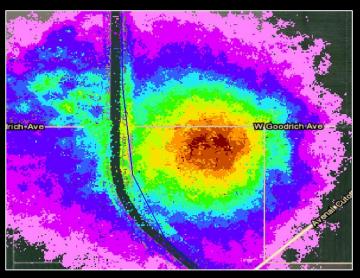
### NASA Research on Land Subsidence Due to Pumping of Groundwater

CA Central Valley



Credits: Canadian Space Agency/NASA/JPL-Caltech

#### CA Aquaduct Near Huron



Credits: Canadian Space Agency/NASA/JPL-Caltech

- How does subsidence correlate with estimates of groundwater availability and well depth measurements?
- What level of rebound was observed during the 2016-2017 water year?



# Potential Science Data Application: Augmenting the data-information found in the State of California Groundwater Information Center (GIC)



Credit: State of California Department of Water Resources (DWR)



# Potential for [Better] Informed Decision-Making: What stage of water conservation measures should be employed this water year?

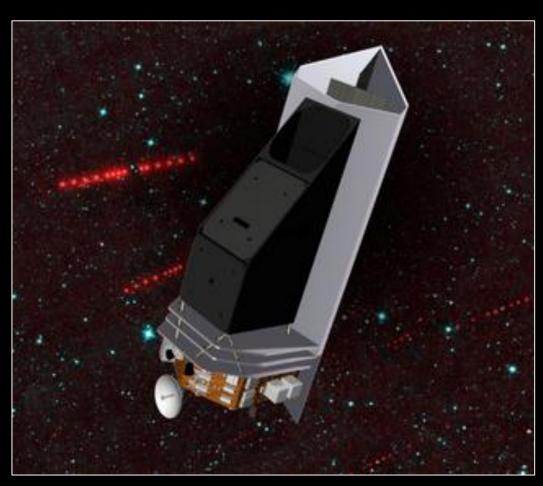


Credit: Metropolitan Water District of Southern California, 2010



## Near-Earth Object Camera (NEOCam)

[Proposed Mission]



- Science Data Application
- ✓ Science/Research
- ✓ Informed Decision-Making

Credit: NASA/Caltech - Jet Propulsion Laboratory



## We must seek to maximize the rate of return on investments by serving the needs of science/research, data applications, and informed decision-making

- Ralph R. Basilio
Presentation to the National Academies
Board on Earth Sciences and Resources (BESR), 09 May 2017



## Thank you to:

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Department of Earth and Environmental Engineering, Columbia School of Engineering and Applied Sciences (SEAS), faculty, researchers, graduate students, and other attendees

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NASA, ESA, CalTech, Arizona State